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Enhancing Students' Critical Thinking Skill Through STEM-Oriented PJBL with *Mind Mapping* Support on Cardiovascular System Material

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Abstract

Background: *this study is the low critical thinking skills of students and the limited learning models that can stimulate it optimally. This study aims to analyse the effect of STEM-based Project-Based Learning (PjBL) learning model assisted by mind mapping on students' critical thinking skills on cardiovascular system material.* **Methodology:** *This research used quasi-experimental method with research design using Pretest Postest Control Group Design. The research sample was XI MIPA class students with the experimental class getting the STEM-based PjBL model treatment assisted by mind mapping, and the control class using conventional learning. The research instrument was a critical thinking skills test based on indicators from Facione (2013). Data were analysed using normality test, homogeneity test, and F test (ANOVA) with 5% significance level.* **Findings:** *The results showed that there was a significant effect of* ***0.000****, meaning that there was a significant difference between the experimental group and the control group simultaneously on students' critical thinking skills after the application of the STEM-based PjBL model assisted by mind mapping. Students in the experimental class showed an increase in the ability to interpret, analyse, evaluate, and draw conclusions from the Cardiovascular system material.* **Contribution:** *These findings suggest that the integration of project-based learning with STEM approach and visualisation through mind mapping is effective in improving students' higher order thinking skills in a meaningful way.*

Keywords: *Critical Thinking; Mind Mapping; Project Based Learning; STEM; Cardiovascular System*

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INTRODUCTION

Along with the passage of time and technology, the world of education has evolved to adapt to rapid changes (Maritsa et al., 2021). In the era of 21st century globalisation, there is a need to make fundamental transformations in various sectors, including industry. Therefore, education needs to continuously improve its quality to remain relevant to the times. This view is in line with the statement of Octafianellis et al., (2021) which emphasises that education today must prepare students with the skills needed in the 21st century. One very important skill is the ability to think critically. Critical thinking ability is the ability to look at a problem or issue from various points of view and assess it objectively and rationally (Ariadila et al., 2023). It involves analysing information obtained, evaluating arguments, looking for evidence that supports or refutes a view, and making decisions that are based on rational and objective analysis. Critical thinking helps us understand information and make informed and quality decisions, helps avoid thinking errors and makes us smarter in understanding and dealing with problems. In addition, critical thinking also helps us avoid thinking errors that often hinder us in achieving our goals. In other words, critical thinking is a powerful tool to achieve success in various aspects of life (Rosmaini, 2023).

In Tafsir Al-Azhar, Buya Hamka revealed that Surah Ali Imran verses 190-191 emphasise the importance of critical thinking and contemplating the wonders of God's creation. These verses invite humanity to pay attention to the signs of Allah's power hidden in the universe, such as the creation of the heavens, the earth, and the cycle of day and night (Nurjanah et al., 2023). This verse invites humans to think critically about natural phenomena, which not only strengthens faith, but also fosters awareness and responsibility. By thinking critically, humans can understand the meaning of life, find evidence of God's greatness, and encourage the emergence of science. Therefore, the development of critical thinking skills needs to be an important goal in education, especially in Indonesia.

What can be done is to teach students to think critically clearly in all lessons. In this way, students are expected to think critically and connect various things around them to make analyses based on their own thinking (Nurhayati et al., 2020). An excellent subject to train critical thinking skills is biology. Biology is the study of living things. Basically, biology as part of science is very broad (Nurtamara et al., 2023). Biology does not only learn about living things, but about living things with all the interactions that occur with the environment. Biology can be studied textually or contextually (Salehah & Rahmatullah, 2023). Learning biology contextually can encourage students to be more active and learning becomes more meaningful, because contextual learning is centred on learner activities. This is in accordance with the term learning according to Jayawardana & Gita (2020) that the term learning (instruction) is heavily influenced by the flow of holistic cognitive psychology, which places students as the source or as the centre of their learning activities.

According to research Ismayanti et al., (2022) results show that the lack of student interest is caused by several factors, one of which is ineffective learning methods. This resulted in students not being actively involved in the learning process.

The result of this lack of interest is the low critical thinking skills of students. This is supported by the data and results of measuring students' critical thinking skills in one of SMA N 16 Medan which still applies teacher-centred learning methods. The test results showed that the percentage obtained by students only reached 35%. From this data, it can be concluded that students' critical thinking skills are still low.

The low level of critical thinking skills in students is partly due to the teacher-centred approach to learning. In this approach, students tend to be passive listeners who receive information from the teacher without actively participating in the learning process (Putri et al., 2022; Sinaga & Simanjuntak, 2020; Marnita et al., 2020). This method does not encourage students to think critically, analyse or evaluate the information provided. In contrast, students who engage in more interactive and collaborative learning, such as project-based learning or group discussions, are more likely to develop critical thinking skills. Thus, the lack of opportunities for students to actively engage and contribute to learning can negatively affect their ability to think critically.

This is further strengthened by research Rachmawati et al., (2024) conducted by which concluded that the use of the lecture method in learning places students in the role of mere listeners and note-takers. In this context, students are not given the opportunity to actively participate or interact with the subject matter. As a result, this approach inhibits the development of their critical thinking skills. Students are limited in exploring ideas, analysing information, and arguing, all of which are important components of critical thinking. With a lack of active engagement, students not only lose motivation to learn, but are also unable to apply the critical thinking skills needed in everyday life and in academic contexts. This is in line with the results of observations made on biology learning in class XI at SMA Negeri 16 Medan, where the teacher still applies the lecture method in the learning process. During the observation, it was seen that students did not play an active role in learning activities in the classroom and tended to be less enthusiastic about the lesson. One of the disadvantages of this lecture method is that students do not get the opportunity to discover concepts by themselves, which results in their low critical thinking skills. Therefore, it is very important to make efforts to create a learning atmosphere that can help students improve their critical thinking skills.

Based on observations made at SMA Negeri 16 Medan, it was revealed that the learning approach applied in the classroom has been favouring conventional methods, such as lectures and repetition of material, where 85 % of students scored below the minimum completion criteria (KKM), which is below 80. This causes students to tend to be passive in the learning process, with the main focus on memorising material without involving their critical thinking skills. In the context of more complex material, such as the cardiovascular system, students often find it difficult to connect the theory taught with real-life applications or phenomena. This one-way learning process also limits students in developing analytical and critical skills that are needed to understand deep biological concepts (Ray et al., 2024). In addition, although the development of critical thinking skills is essential, the approaches used do not adequately support the development of these skills. As a result, students' ability to analyse and solve problems related to biological materials, particularly on complex topics such as the cardiovascular system, is severely limited (Novitasari et al., 2025; Candraswari & Suniasih, 2024; Nadia et al., 2023).

Under these conditions, innovation in learning models in the biology classroom is needed to increase student engagement and critical thinking skills. One solution that can be applied is the use of a project-based learning (PJBL) model integrated with a STEM-based approach (Science, Technology, Engineering, Mathematics). The STEM-based PJBL model allows students to be more actively involved in learning through real projects that connect theoretical concepts with practical applications (Pramasdyahsari, 2023). This is expected to deepen students' understanding and improve their critical thinking skills. In addition, the use of Mind Mapping as an assistive technique in learning can also clarify the relationship between concepts visually and systematically, thus assisting students in organising their knowledge and stimulating analytical thinking (Nazifa et al., 2025). Given the challenges faced in learning the cardiovascular system, the implementation of STEM-based PPA assisted by Mind Mapping is expected to be an effective solution to improve students' critical thinking skills, as well as their understanding of more complex material. Therefore, this study aims to investigate the effect of implementing a STEM-based PPA learning model supported by Mind Mapping on improving students' critical thinking skills on cardiovascular system material at SMA Negeri 16 Medan.

In this regard, the application of the Project-Based Learning (PJBL) learning model combined with the use of mind mapping by researchers aims to improve students' critical thinking skills. The PjBL Learning Model is a thinking activity that can improve critical thinking skills. The PjBL learning model has advantages in improving learning habits and motivating students to think originally in solving a problem in real life (Jannah et al., 2023). In project learning the teacher as a facilitator, collaborates with students in making useful questions and meaningful tasks, so as to develop knowledge and social skills and assess students from their learning experience (Fajri et al., 2024). Mind mapping serves as a visual aid that allows students to structure and organise information more effectively. By using mind mapping, students can put the ideas and information they have obtained in a more structured form, making it easier for them to analyse and relate the concepts learned (Handayani et al., 2024). Mind mapping media can stimulate critical thinking because it encourages students to think creatively and connect various ideas. In this process, students are expected not only to remember information, but also to be able to develop a deeper understanding of the material being taught. By creating concept maps, students can see the relationship between information and identify patterns, thus improving their analysis and evaluation skills (Kumalasari et al., 2024).

Based on the description of the background and problems, the purpose of this study is to examine the effect of STEM-based Project-Based Learning (PJBL) model supported by mind mapping on students' critical thinking skills on cardiovascular system material. This research needs to be done because it can provide insight into how this combination of approaches affects students' critical thinking skills. The results are expected to show that the integration of PPA and mind mapping models can stimulate students' analytical, evaluative, and reflective thinking, while deepening their understanding of complex scientific concepts.

METHOD

This type of research is *quasi experimental* research (Quasi Experiment) (Suparman et al., 2020). where the experimental research approach is used to find the effect of applying the STEM-based PjBL learning model on students' critical thinking skills by involving experimental classes that are treated using the STEM-based PjBL learning model assisted by mind mapping, as well as control classes that are treated with conventional learning models. The Research Design uses Pretest Postest Control Group Design (Pratami et al., 2019).

Sample or Participant

The population in this study were all students of the Natural Science programme in class XI at SMA N 16 Medan who studied Cardiovascular System material in biology learning. The intended population consisted of 100 students, which were divided into 4 MIPA classes. Each of these classes has similar characteristics in terms of academic ability level and interest in biology lessons, so it is considered to represent the relevant population for this study (Aini et al., 2024).

The sample in this study is part of the population chosen to be the object of research. The sample selection was carried out using *cluster random sampling*, which is a sample selection technique in which all classes are used as groups, and then the classes are randomly selected to be the research sample (Asrulla et al., 2023). In this study, two classes were randomly selected, one of which would be the experimental class (which was given treatment using the STEM-based PJBL learning model assisted by mind mapping), and the other class became the control class (which was given conventional learning).

Instrument

The research instrument used is a critical thinking skills test in the form of an essay of 6 items. This instrument refers to 6 critical thinking indicators put forward by Facione (2013) namely interpretation, analysis, inference, evaluation, explanation, and self-regulation (Ningtyas & Rahayu, 2022). The instrument will be validated by a validator so that the final results will be obtained which are suitable for use as research.

Data collection

The methods used to collect data are observation, test and documentation. Observation results were carried out on students' critical thinking behaviour while they were learning using STEM-based PJBL with mind mapping. The tests used were pre-test and post test in the form of essays. Tests are given to obtain quantitative data, namely data on student learning outcomes after receiving learning that can be analysed descriptively. Researchers give tests to students at the end of learning to determine the level of mastery of students in learning biology on the material of the cardiovascular system that has been studied. Documentation in this study there is also the collection of data sources that come from non-human, documents, and photographs.

Procedure

This research is divided into 3 stages, namely, the preparation stage, the implementation stage, and the completion stage. The preparation stage carried out is the observation stage first, determining the research population, compiling a Learning Implementation Plan (RPP), making Learner Worksheets (LKPD), making a lattice of assessment instruments, making essay questions, testing test instruments to biology expert lecturers.

The activities carried out at the implementation stage are, giving a pre-test to students before carrying out the learning process consisting of 5 essay test questions, carrying out the learning process of cardiovascular system material using the Project Based Learning (PJBL) learning model by providing (LKPD) which contains learning activities in accordance with the PJBL syntax. PJBL syntax in learning can be seen in table 1.

Table 1. Syntax of *Project Based Learning* Model Activities

Meeting	PPA syntax	Learning Activities	Project Products	Facilitating Critical Thinking Skills
1	Fundamental Questions & Project Planning	- The teacher raises a problem: What happens if the circulatory system is disrupted? - Students have an initial discussion and make a mind map (STEM-based). - Students develop a project plan: normal and abnormal blood flow model.	- Initial mind map: cardiovascular system (normal vs abnormal). - Draft project plan (tools/materials/rare).	- Problem interpretation and clarification. - Analyse cause-and-effect relationships. - Develop preliminary arguments. - Make preliminary decisions based on evidence.

Meeting	PPA syntax	Learning Activities	Project Products	Facilitating Critical Thinking Skills
2	Research and Data Collection	- Observation and exploration of the anatomy of the circulatory system. - Literature study (science, technology, medical, etc). - Analyse differences in normal vs impaired blood circulation (e.g. blockages, heart failure).	- Report on preliminary research results. - Development of project design based on scientific data.	- Data analysis. - Evaluation of information sources. - Scientific inference based on facts. - Testing the validity and relevance of information.
3	Project Product Creation	- Students create models of normal and abnormal blood flow (3D materials or interactive digital). - STEM implementation in the creation (simple technology, visualisation, simulation).	- Cardiovascular system model: 2 versions (normal and impaired). - Manual/simulation of system work.	- Complex problem solving. - Synthesis of ideas into tangible products. - Integrating knowledge between fields. - Reflective thinking during the creation process.
4	Presentation, Evaluation, and Reflection	- Groups present their products and explain how the system works. - Give each other feedback (peer review). - Reflection on the learning process and critical thinking.	- Video/photo documentation of the project. - Final mind map + individual reflection report.	- Evaluation of arguments and solutions. - Self-reflection on the thinking process. - Ability to explain and defend ideas. - Constructive criticism of other groups' solutions.

Data analysis

The data analysis technique that the authors used in this study used quantitative data analysis, the data analysis technique was tested using statistical tests. Before testing the hypothesis, the prerequisite test was first carried out, namely the normality test and the homogeneity test with Shapiro-Wilk. Next is the hypothesis test using the F (Simultaneous) test on the SPSS programme, with a significant level of 5 %. The study used this test because the study used two unrelated samples, namely having an experimental class and a control class to test the difference between the two samples (Yusnarti & Suryaningsih, 2021).

RESULT AND DISCUSSION

The research data was obtained from tests given to the research sample. There are two tests used, namely *PreTest* and *PostTest*. *PreTest* was conducted to see students' initial knowledge while *PostTest* was conducted to see students' knowledge after being given treatment in learning by using the STEM-based PJBL learning model *assisted by Mind Mapping.* The results of the average scores achieved by students on the *PreTest* and *PostTest scores of* the experimental and control classes are presented in Figure 1.

Based on the data obtained, the initial achievement results of experimental class students were 38.32 with a minimum score of 17 and a maximum score of 54. While the final achievement of experimental class students averaged 61.86 with a minimum score of 33 and a maximum score of 83. So it can be seen that there is an increase in student learning achievement in the experimental class. While for the control class in the initial achievement of students the average value was 20.63. with a minimum value of 4 and a maximum value of 34. While for the final achievement of students the average value was 49.3 with a minimum value of 21 and a maximum value of 75.

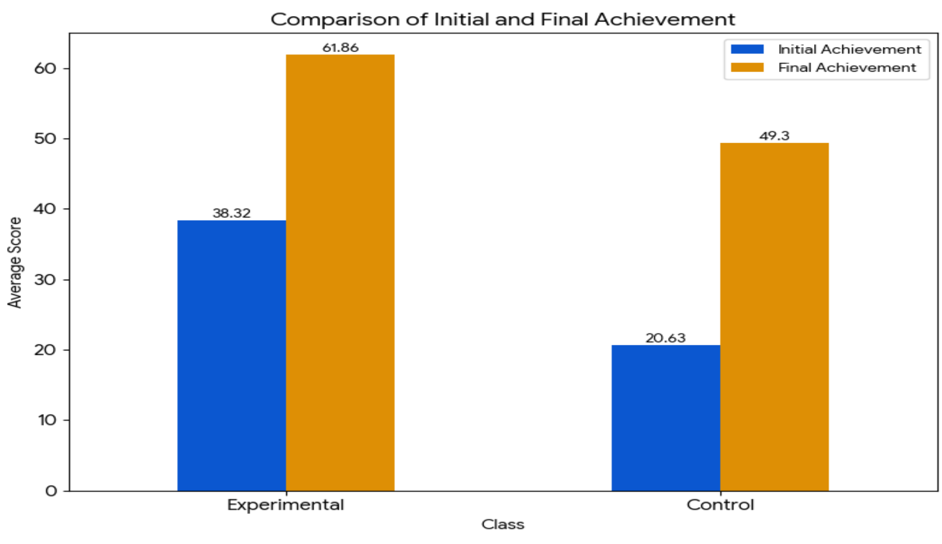

Figure 1 Diagram of the average scores of students in the Experimental and Control classes

After the student achievement data from the experimental and control groups were collected, the first step was to conduct two types of preliminary tests to ensure the appropriateness of the data before further analysis. The first test is the normality test, which aims to ensure that the student achievement data is normally distributed and does not show a distribution pattern that is skewed to one side. The second test is the homogeneity test, which is used to determine whether the variance or distribution of student achievement data between the two groups - namely the experimental group and the control group - is uniform or equal. After the results of the two tests showed that the data fulfilled the assumptions of normality and homogeneity, the analysis continued by conducting an F test through one-way ANOVA. This test is used to determine whether there is a statistically significant difference between the average student achievement in the experimental group and the control group, so that it can be concluded whether the treatment given to the experimental group has a real influence on student learning outcomes.

Table 2. Normality Test of Experimental and Control Classes

Class	**Tests of Normality**					
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**Df**	**Sig.**	**Statistic**	**Df**	**Sig.**
Control Class Pree test (Conventional)	.182	30	.013	.951	30	.176
Control Class Post Test (Conventional)	.142	30	.129	.959	30	.291
Experiment Class Pree Test (PJBL)	.143	50	.012	.967	50	.174
Post Test Experiment (PJBL)	.111	50	.174	.970	50	.230

Based on the results of the Shapiro-Wilk normality test, all data showed a significance value > 0.05, namely 0.176; 0.291; 0.174; and 0.230, which indicates that the distribution of student achievement data in the experimental and control groups is normal. After that, a homogeneity test was conducted to ensure that the data variance between the two groups was the same.

Table 3. Test of Homogeneity of Pre Test Experiment and Control

RESULTS	**Homogeneity Test of Variance**			
	Levene Statistic	**df1**	**df2**	**Sig.**
Based on Mean	1.262	1	78	.265
Based on Median	1.350	1	78	.249
Based on Median and with adjusted df	1.350	1	77.511	.249
Based on trimmed mean	1.221	1	78	.273

Based on the results of the homogeneity test, the significance values were 0.265; 0.249; 0.249; and 0.273. All of these values are above the threshold > 0.05, so it can be concluded that the data has a homogeneous or uniform variance between groups. After the data were declared to fulfil the assumptions of normality and homogeneity, the analysis continued with the F test through one-way ANOVA to determine whether there was a significant difference between the average student achievement in the experimental group and the control group. This test is used because it is suitable for comparing two or more groups that fulfil parametric assumptions, namely normal distribution and homogeneous variance. If the ANOVA test results show a significance value (Sig.) of less than 0.05, it can be concluded that there is a statistically significant difference between the groups studied, which means that the treatment or intervention given to the experimental group has an effect on student learning outcomes.

Table 4. ANOVA Test of Post Test of Experiment and Control

RESULT	ANOVA				
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	3363.401	1	3363.401	26.975	.000
Within Groups	9725.487	**78**	124.686		
Total	13088.887	**79**			

Based on the results of the ANOVA F test which shows a significance value (Sig.) of **0.000**, it can be concluded that there is a significant difference between the experimental group and the control group. The experimental group that used the *Project-Based Learning* (PJBL) learning model showed statistically higher results compared to the control group. The PJBL learning model, which emphasises the active involvement of learners in real projects to solve problems, is proven to have a significant positive effect on improving students' critical thinking skills and learning outcomes. These results directly support the hypothesis that the implementation of PPA contributes to significantly improving student learning outcomes compared to conventional learning methods.

To strengthen the results of the quantitative analysis, a questionnaire was distributed to students in the experimental group to identify their responses to the learning process that had been implemented. The results of the questionnaire data processing showed an average score of **80.64**, which is in the **good** category. This finding reflects that learners not only obtained statistically better learning outcomes, but also showed a positive response to the learning experience using the PPA approach. The high questionnaire scores indicate that students felt more motivated, actively involved, and encouraged to think critically and reflectively during the project-based learning activities. Thus, this questionnaire data supports the ANOVA test results, as well as providing triangulative evidence that PJBL plays an important role in encouraging the achievement of holistic learning outcomes from both cognitive and affective aspects.

From the data obtained in the research results, it is known that there is an increase in student learning outcomes that are influenced by the learning model applied during the learning process. This increase shows that learning strategies have an important role in shaping students' conceptual understanding and thinking skills, especially in complex material such as the cardio-vascular system. Project-Based

Learning (PJBL) model is one of the learning approaches that places students as the centre of learning activities through direct experience of completing projects. In the context of this research, the PPA model is combined with the STEM (Science, Technology, Engineering, and Mathematics) approach and reinforced with a visualisation strategy in the form of mind-mapping as a concept mapping tool.

Learning activities were conducted in two different groups. The experimental class was treated with a STEM-based Project-Based Learning model supported by the use of mind-maps to help students organise complex ideas and concepts. In contrast, the control class followed a conventional learning process, which was dominated by the lecture method and passive learning activities such as note-taking and memorisation. Although both learning models showed changes in students' understanding of the material, the results obtained in the experimental class showed a much more significant improvement.

The higher value increase in the experimental class can be seen from the post-test results. After being given the treatment of learning with the STEM-based PJBL model assisted by mind-mapping, the average value of experimental class students increased significantly to 61.86. Meanwhile, students in the control class who received conventional learning only reached an average of 49.3. This difference is an important indicator that the STEM-based PPA approach is able to provide a deeper and more meaningful learning experience compared to the one-way lecture method. In with Octafianellis et al., (2021) which states the STEM Student's have a significant impact on Critical Thinking Skills and Creativity.

From the data above, it can be seen that the selection of the right learning model and in accordance with the characteristics of the material and the needs of students will have a significant impact on concept understanding. This is in line with the opinion of Zahroh (2020) which states that the PJBL model is the right approach to improve students' understanding and thinking skills because it encourages active involvement, collaboration, and the development of problem-solving skills. Fajri et al., (2024) PJBL allows students to experience the learning process directly through exploration and investigation, not just passively receiving information.

The results of normality and homogeneity tests carried out before the main analysis aim to ensure that the data meet the requirements for parametric tests. Based on the results of the Shapiro-Wilk test, it is known that all groups of data have a significance above 0.05. This indicates that the data is normally distributed. In addition, the homogeneity test using Levene's Test shows that the variance between data groups is also homogeneous, as evidenced by the significance value above 0.05 in all calculation methods (mean, median, trimmed mean). With the fulfilment of these two assumptions, the data is worthy of further analysis using the one-way ANOVA test to see the effect of learning models on student learning outcomes.

The ANOVA test conducted resulted in a significance value of 0.000. This value is far below the significance limit of 0.05, which statistically indicates that there is a very significant difference between the group that received the treatment of STEM-based PJBL model assisted by mind-mapping and the group that received conventional learning. In other words, the treatment in the form of an innovative learning model applied to the experimental class proved to have a real impact on

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improving student learning outcomes, especially in the aspect of critical thinking. These results strongly support the research hypothesis that the PPA model can improve student understanding better than conventional learning methods.

Conceptually, the success of the STEM-based PJBL model in improving student learning outcomes is inseparable from the learning approach that emphasises active, exploratory and reflective processes. Students in the experimental class were trained to be directly involved in designing projects, analysing data, making conclusions and presenting results, all of which are part of critical thinking skills. In line with Kumalasari et al., (2024) The integration of mind-mapping in learning also supports students' cognitive processes as it helps them visually map and link concepts, thus strengthening their understanding and recall of complex material such as the cardio-vascular system.

Based on the results of statistical analysis and empirical findings described above, it can be concluded that there is a significant effect of the application of STEM-based Project-Based Learning model assisted by mind-mapping on students' critical thinking skills. Because the significance value of the ANOVA test results is smaller than 0.05, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted, which means that the application of the STEM-based PJBL model assisted by mind-mapping significantly improves student learning outcomes compared to conventional learning. Thus, this model can be recommended as an effective learning approach to improve students' understanding and critical thinking skills in learning biology and other science fields.

As an effort to strengthen the quantitative findings from the ANOVA test results, a questionnaire was also distributed to students in the experimental group. This questionnaire aims to explore students' responses to the learning process they experienced while using the STEM-based Project-Based Learning model with the help of *mind-mapping*. Based on the results of the questionnaire data processing, an average value of **80.64** was obtained, which was categorised in the **good** classification. The average score shows that most students gave a positive assessment of the application of the PJBL model in learning biology, especially on cardio-vascular system material. The students admitted that it was easier to understand the material, more active in the learning process, and felt helped by the use of mind-maps in organising and connecting complex concepts. In line with Nazifa et al., (2025) This finding strengthens the assumption that project-based learning that is contextual, interactive and visualised through concept mapping can create a more meaningful and enjoyable learning experience.

Furthermore, this questionnaire data provides additional evidence that PJBL not only impacts on improving cognitive learning outcomes, but also affects students' affective aspects, such as motivation, self-confidence, and positive attitudes towards the learning process. This is in line with the view of Agusdianita et al., (2023) which asserts that PJBL is a holistic approach that not only targets conceptual understanding, but also forms independent, collaborative, and reflective student characters. Thus, the high value of the questionnaire strengthens the validity of the main findings of this study, and provides a strong empirical basis that the STEM-based PPA model assisted by mind-mapping is a feasible learning approach to be applied in order to comprehensively improve students' critical thinking skills and learning outcomes.

CONCLUSIONS

Based on data analysis and statistical test results (one-way ANOVA), it was found that the STEM-based Project-Based Learning (PJBL) learning model aided by mind-mapping has a significant effect on students' critical thinking skills on cardiovascular system material, with a significance value of 0.000 (<0.05) which shows a significant difference in learning outcomes between the experimental class (average 61.86) and the control class (average 49.3). This finding proves that project-based learning with STEM integration and the use of mind-mapping as a visualisation tool promotes an active and immersive learning experience, while improving students' critical thinking skills. Therefore, teachers are advised to apply this model, students are expected to be more active in using mind-mapping, schools should support with facilities and policies that support contextual learning, and further research is recommended to apply the PJBL-STEM model assisted by mind-mapping to other materials or levels of education to strengthen the generalisation of the results.

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